Phase Effects on Mesoscale Object X-Ray Absorption Images

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At Lawrence Livermore National Laboratory, we are placing particular emphasis on the NDC of "mesoscale" objects. We define mesoscale objects as objects that have mm extent with μm-sized features. Here we confine our discussions to x-ray imaging methods applicable to mesoscale object characterization.

Project Goals

Our goal is the development of object recovery algorithms, including phase, to enable emerging high-spatial-resolution x-ray imaging methods to "see" inside, or image, mesoscale-size materials and objects. To be successful, our imaging characterization effort must be able to recover the object function to 1 μm^3 or better spatial resolution over a few mm × mm field-of-view, with very high contrast.

Relevance to LLNL Mission

Specific LLNL programs that would benefit from this new capability include the development of novel sensors for NAI applications; the study of explosive samples for DoD, DOE; and high-energy-density physics and inertial confinement fusion experiments for NIF.

FY2004 Accomplishments and Results

Our approach includes the research, development, and validation of algorithms to model phase-contrast effects observed in x-ray systems, and to use these algorithms for quantitative object recovery. This requires three tasks.

First, we are modifying HADES to model phase effects for point projection imaging, and investigating whether multi-slice techniques within the object are needed to fully capture the physics seen in phase-contrast data. Second, we are developing several object recovery approaches using parameter-based and voxel-based techniques. Third, we are validating these simulations against x-ray systems using well-known objects. At the end of this R&D, we will have a set of validated x-ray codes for modeling and reconstructing objects, including the effects of phase.

We have extended HADES to be able to calculate both the x-ray attenuation and phase of complex objects, a capability that is already showing relevance to other LLNL projects.

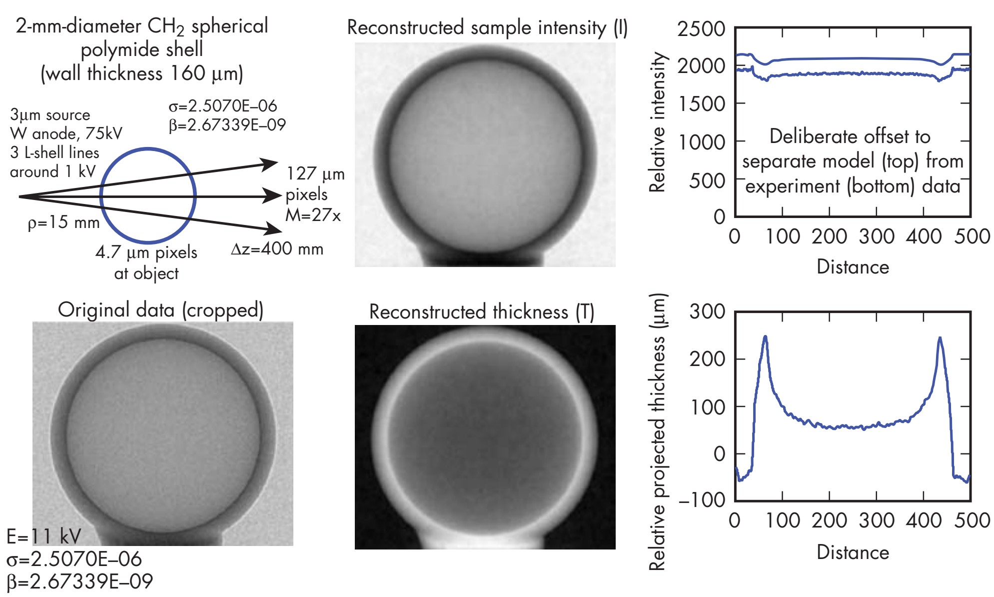

Figure 1. Application of the single-material reconstruction algorithm to LLNL's KCAT data of a polystyrene sphere.

We have reached the point in x-ray imaging where the spatial resolution and object dimensions could theoretically result in the wave diffraction effects within the sample becoming significant. We studied this possibility and determined that diffraction effects on the measured data will be insignificant.

Typically more than one image is required to separate the object phase and absorption structure. However, for the case of an object composed of a single material, both the projected phase and the amplitude through an object are directly related to the projected material thickness. This enables the object to be described in a single variable, the object thickness, as opposed to two variables, amplitude and phase. This in combination with the transport of intensity equation yields a strategy for reconstructing the object taking into account phase effects in the detected image. This approach has been implemented numerically (Fig.1).

Continued modeling has identified that there is a shift in position of key features within an object that can be explained only by incorporating phase effects into the system modeling (Fig. 2).

A key part of this proposed project is the validation of the simulation and object-recovery codes. Two things are required to validate x-ray simulation codes: the x-ray system being modeled, and a well-known object (also known as a phantom or reference standard). We have designed a multislice phantom that can be modeled and used to validate the simulations (Fig. 3).

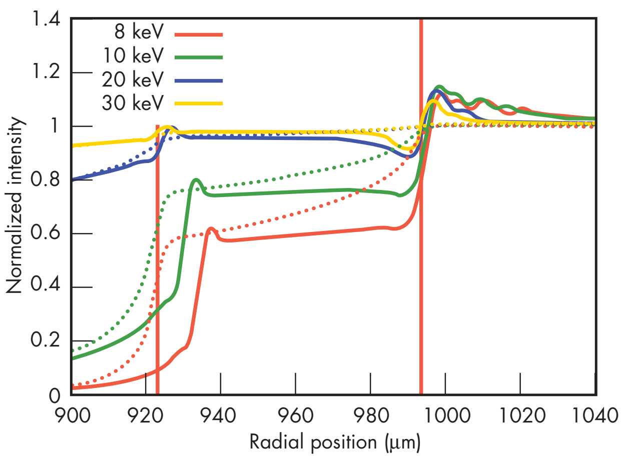

Figure 2. Simulated results for x-ray imaging of a CVD diamond shell coated on a SiN mandrel. The image shows the shift in position of the interface with energy. Results with phase effects included are shown by the solid lines. Results with no phase effects are shown by the dashed lines. Note the dramatic difference in the phase data as a function of energy (due to the change in refractive index) compared with the results for no phase.

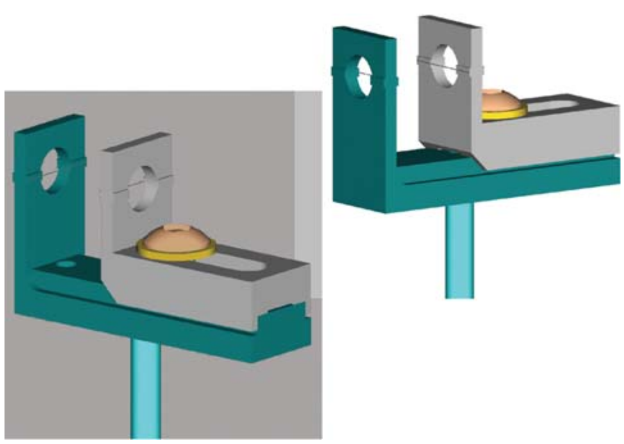

Figure 3. Phantom designed to validate the multislice (also known as the beam propagation) method to solve the paraxial wave equation to simulate x-ray microscopy of mesoscale objects and determine if ray tracing within the object will suffice. The phantom has two carbon fibers of 6-μm diameter that can be placed at different locations (0 to 10 mm) along the x-ray beam axis.

Related References

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2. Aufderheide, M. B., A. Barty, and H. E. Martz, "Simulation of Phase Effects in Imaging for Mesoscale NDE," LLNL, UCRL-CONF-206263, submitted to *Review of Progress in Quantitative Nondestructive Evaluation,* 2004.
3. Barty, A., K. A. Nugent, A. Roberts, and D. Paganin, "Quantitative Phase Tomography," *Opts. Comm.*, **175**, pp. 329-336, 2000.
4. Martz Jr., H. E., and G. F. Albrecht, "Nondestructive Characterization Technologies for Metrology of Micro/Mesoscale Assemblies," *Proceedings of Machines and Processes for Microscale and Mesoscale Fabrication, Metrology, and Assembly*, ASPE Winter Topical Meeting, Gainesville, Florida, January 22-23, pp. 131-141, 2003.

FY2005 Proposed Work

We will focus on 2-D simulations and uniform object recovery. HADES incorporation of phase effects and the multislice code will be validated using phantoms. Object recovery algorithms will be investigated and validated for uniform single material objects and parametric reconstructions using HADES.